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THE BEHAVIOR OF REGULAR AND IRREGUALR REINFORCED CONCRETE BUILDINGS UNDER VARYING SEISMIC FREQUENCY CONTENTS

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Abstract - *Earthquake has social as well as economic consequences such as causing death and injury of living things especially human beings and damages the built and natural environment. Proper selection of seismic design forces for engineering structures requires specification of the expected intensity of ground shaking that the structure will experience during their lifetime. Earthquake is the result of sudden release of energy in the earth's crust that generates seismic waves. Ground shaking and rupture are the major effects generated by earthquakes. In order to take precaution for the loss of life and damage of structures due to the ground motion, it is important to understand the characteristics of the ground motion.*

The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. The more common practice adopted by many seismic codes is to use peak acceleration as a single measure of ground motion intensity. However, as more earthquake records were obtained, it became apparent that the use of a single design spectral shape scaled by peak site acceleration is inadequate to cover over all sites. Many recorded earthquake ground motions have response spectra dramatically different from the standard design spectrum. Ground motion has different frequency contents such as low, intermediate, and high. These characteristics play predominant rule in studying the behavior of structures under seismic loads. The strength of ground motion is measured based on the PGA, frequency content and how long the shaking continues.

The response of the buildings due to the ground motions in terms of storey displacement, storey velocity, storey acceleration, and base shear are found. The responses of each ground motion for each type of building are studied and compared. The results show that low- frequency content ground motions have significant effect on both regular as well as irregular RC buildings. However, high-frequency content ground motions have very less effect on responses of the regular as well as irregular RC buildings.

Key Words: Reinforced concrete buildings, ground motion, peak ground acceleration, frequency content, time history analysis

1. INTRODUCTION

An earthquake is the result of a rapid release of strain energy stored in the earth crust that generates seismic waves Structures are vulnerable to earthquake ground motion and damages the structures. In order to take precaution for the damage of structures due to the ground motion, it is important to know the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. These characteristics play predominant rule in studying the behaviour of structures under the earthquake ground motion.

The earth vibrates continuously at periods ranging from milliseconds to days and the amplitudes may vary from nanometers to meters. The motion that affects living beings and their environment is of interest for engineers and is termed as Strong ground motion. The Motion of the ground can be described in terms of displacement, velocity, or acceleration. The variation of ground acceleration with time, recorded at a point on the ground during an earthquake is called an accelerogram. The ground velocity and displacement can be obtained by direct integration of an accelerogram. Typical ground motion records are called time histories-the acceleration, velocity and displacement time histories. From an engineering point of view, the peak ground acceleration, frequency content, and the duration of motion are the three important characteristics of the ground motion parameters. These characteristics play predominant rule in studying the behaviour of structures under the earthquake ground motion. The responses of RC buildings are strongly dependent on the frequency content of the ground motions. The frequency content (distribution of energy with respect to frequencies) of an accelerogram is represented by Fourier spectrum, Power spectrum, and Response spectrum.

Based on the frequency content, which is the ratio of PGA/PGV the ground motion records are classified into three categories,

1. High –Frequency content PGA/PGV>1.2
2. Intermediate-frequency content 0.8≤PGA/PGV≤1.2
3. Low Frequency content PGA/PGV<08

The ratio of peak ground acceleration in terms of acceleration of gravity (g) to peak ground velocity in unit of (m/s) is defined as the frequency content of the ground motion. The present work shows that how reinforced concrete buildings behave under low, intermediate, and high-frequency content ground motions Severe earthquakes happen rarely. Even though it is technically conceivable to design and build structures for these earthquake events, it is for the most part considered uneconomical and redundant to do so. The seismic design is performed with the expectation that the severe earthquake would result in some destruction, and a seismic design philosophy on this premise has been created through the years. The objective of the seismic design is to constraint the damage in a structure to a worthy sum. The structures designed in such a way that should have the capacity to resist minor levels of earthquake without damage, withstand moderate levels of earthquake without structural damage, yet probability of some non-structural damage, and withstand significant levels of ground motion without breakdown, yet with some structural and in addition non-structural damage.

In present work, three, seven, and twenty two-storey regular as well as irregular RC buildings are subjected to seven ground motions of low, intermediate, and high-frequency content. The buildings are modelled as three dimension and linear time history analysis is performed using structural analysis and design (STAAD Pro)

1.1 OBJECTIVE AND SCOPE

The purpose of this project is to study the response of low, mid, and high-rise regular as well as irregular three-dimension RC buildings under low, intermediate, and high-frequency content ground motions in terms of storey displacement, storey velocity, storey acceleration and base shear preforming linear time-history analysis using STAAD Pro [1] software. From the three dynamic characteristics of ground motion, which are PGA, duration, and frequency content, keeping PGA and duration constant and changing only the frequency content to see how low, mid, and high-rise reinforced concrete buildings behave under low, intermediate, and high-frequency content ground motions.

1.2 METHODOLOGY

The following seven ground motion records, which have low, intermediate, and high-frequency content, have been considered for the analysis:

1. 1979 Imperial Valley-06 (Holtville Post Office) 225 component
2. 1991 Uttarkashi (Bhatwan)
3. 1998 India Burma Boarder (Bokajan, India) 34 component
4. 1991 Uttarkashi (Tehri) 27 component
5. 1992 Landers (Fort Irwin) FTI000 component
6. 1991 Uttarkashi (Uttarkashi) 75 component

Ground motion records are selected from Center for Engineering Strong Motion Data, Strong Motion Virtual Data Center (VDC) Global Component of the Center for Engineering Strong Motion Data.

All the above six ground motions duration is 25 s. In order to have same PGA, the above ground motions are scaled to magnitude of 0.2 g. Three, seven, and twenty two-storey RC buildings, which are considered as low, mid, and high-rise reinforced building are modeled as three-dimension regular and irregular reinforced concrete buildings in STAAD Pro [1]. Then the ground motions are introduced to the software and linear time historey analysis is performed.

The basis of the present work is to study the behavior of reinforced concrete buildings under varying frequency contents. This study shows how low, mid and high-rise reinforced concrete buildings behave in low, intermediate, and high-frequency content ground motions.

Here, the storey displacement, storey velocity, storey acceleration, and base shear of low, mid, and high-rise regular and irregular reinforced concrete buildings due to the seven ground motions of low, intermediate and high-frequency content are obtained. The methodology, which is conducted, is briefly described as below:

1. Ground motion records are collected and then normalized.
2. Linear time history analysis is performed in STAAD Pro .

3. Building response such as storey displacement, storey velocity, storey acceleration, and base shear are found due to the ground motions.

4. The results of the three regular and irregular RC buildings are compared with respect to the six ground motions.

2. STRUCTURE MODELING

Concrete is the most widely used material for construction. It is strong in compression, but weak in tension, hence steel, which is strong in tension as well as compression, is used to increase the tensile capacity of concrete forming a composite construction named reinforced cement concrete. RC buildings are made from structural members, which are constructed from reinforced concrete, which is formed from concrete and steel. Tension forces are resisted by steel and compression forces are resisted by concrete. The word structural concrete illustrates all types of concrete used in structural applications

The plan, three, seven, and twenty two-storey regular reinforced concrete buildings of low, mid, and high-rise are shown. Gravity loads, dead as well as live loads, are given in section. A brief description is provided for concrete and steel. Also, the concrete and steel bar properties which are used for modelling of the buildings are shown At the end of this the sizes of structural elements are presented.

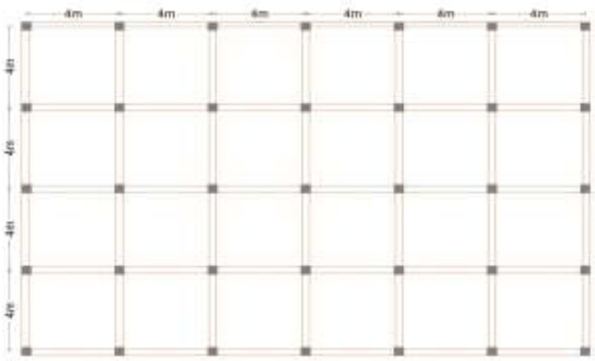

Figure 1 Plan of three, seven, and twenty two-storey regular RC buildings (all dimensions are in m)

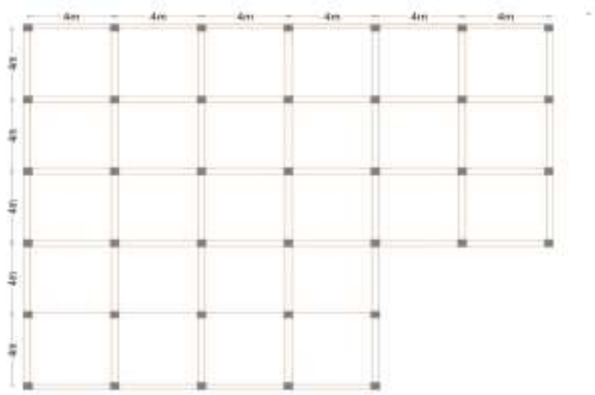

Figure 2 Plan of three, seven, and twenty two-storey irregular RC buildings (all dimensions are in m)

Here the plan configurations of the three, seven, and twenty two-storey RC buildings and their lateral force resisting systems contain re-entrant corners, where both projections of the buildings beyond the re-entrant corner are 40 percent, which is more than 15 percent of their plan dimension with respect to their direction. Therefore, the corresponding RC buildings are considered as irregular structures.

$A1/L1>0.15$ (8/24=0.3>0.15)

$A2/L2>0.15$ (8/20=0.4>0.15)

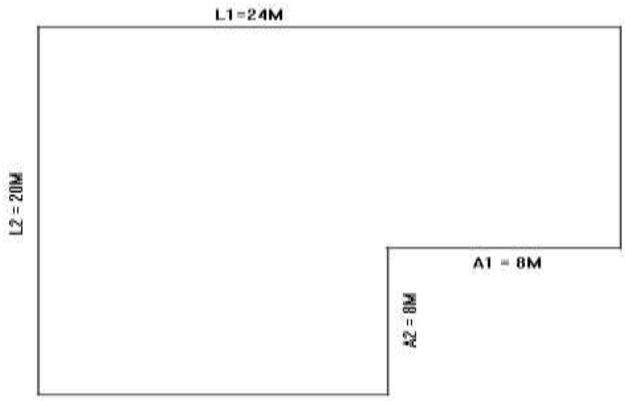

Figure 3 Re-entrant corners as per Table 4 of IS 1893 (Part1) : 2002

For seismic weight, total dead load and 50 percent of live load is considered as per Table 8 of IS 1893 (Part1) : 2002. For calculation of seismic weight, no roof live load is taken.

Table 1: Gravity loads which are assigned to the RC buildings

Gravity Load	Value
Slab Load	3.75 KN/M2
Finish Load	1 KN/M2
Wall Load	10.98 KN/M
Parapet Load	3.27 KN/M
Live Load	3.5 KN/M2

Table 1: Concrete and steel bar properties as per IS 456

Concrete Properties		**Steel Bar Properties**	
Unit weight (γ_c)	25 (kN/m3)	Unit weight (γ_s)	76.9729 (kN/m3)
Modulus of elasticity (E_c)	22360.68 (MPa)	Modulus of elasticity (E_s)	2x105 (MPa)
Poisson ratio (ν_c)	0.2	Poisson ratio (ν_s)	0.3
Thermal Coefficient (α_c)	$5.5\text{x}10^6$	Thermal coefficient (α_s)	$1.170\text{x}10^{-6}$
Shear modulus (G_c)	9316.95 (MPa)	Shear modulus (G_s)	76923.08 (MPa)
Damping ratio (ς_c)	5 (%)	Yield strength (F_y)	415 (MPa)
Compressive strength (F_c)	30 (MPa)	Tensile strength (F_u)	485 (MPa)

Table 3:Beam and Column length and cross section dimensions

Structural Element	Cross section (mm * mm)	Length (m)
Beam in (x) transverse direction	230 x 600	4
Beam in (z) longitudinal direction	230 x600	4
Column	450 x 450	3

Table 4. shows six ground motion records with their characteristics and classified as low, intermediate and high-frequency content. Table 4.3 shows the six ground motions with 25 s duration. As shown in the Table 4.2 and 4.3, the 1979 Imperial Valley-06 (Holtville Post Office) 225 component has 0.5182 < 0.8 PGA/PGV value, hence, it is defined as low-frequency content ground motion. Likewise, the 1991 Uttarkashi (Bhatwari) 335 component as intermediate-frequency content, 1998 India Burma Boarder (Bokajan, India) 34 component as high-frequency content ground motions. The same manner, 1991 Uttarkashi (Tehri) 27 component , 1992 Landers (Fort Irwin) FTI000 component, and 1991 Uttarkashi (Uttarkashi) 75 component are classified as low, intermediate, and high-frequency content ground motions respectively.

Table 4.: Ground motion characteristics and classification of its frequency-content

Records (Stations)	Componet	Magnitutde	Epicenteral Distance (m)	Duration (s)	Time Step for response	PGA(g)	PGV(m/s)	PGA/PGV	Frequency content Classification
1979 Imperial Valley -16 (Holtville post Office)	225	6.6	20.16	37.871	0.02	0.247	0.519	0.477	Low
1991 Uttarkashi (Bhatwari, India)	355	7	21.7	39.72	0.02	0.25	0.298	0.838	Intermediate
1998 India Burma Boarder (Bokajan, India)	34	7.2	189.9	57.78	0.02	0.151	0.086	1.74	High
1991 Uttarkashi (Tehri, India)	27	7	50.6	28.58	0.02	0.062	0.092	0.671	Low
1992 Landers (Fort Irwin)	FTI0	7.28	66.8	79.28	0.02	0.113	0.095	1.187	Intermediate
1991 Uttarkashi (Uttarkashi, India)	75	7	34	39.9	0.02	0.31	0.195	1.589	High

Table 5: Ground motion characteristics and classification of its frequency-content for 25 s duration

Records (Stations)	Componet	Magnitutde	Epicenteral Distance (m)	Duration (s)	response componets (s)	PGA(g)	PGV(m/s)	PGA/PGV	Frequency content Classification
1979 Imperial Valley -16 (Holtville post Office) (GM1)	225	6.6	20.16	25	0.02	0.247	0.519	0.477	Low
1991 Uttarkashi (Bhatwari, India) (GM2)	355	7	21.7	25	0.02	0.25	0.298	0.838	Intermediate
1998 India Burma Boarder (Bokajan, India) (GM3)	34	7.2	189.9	25	0.02	0.151	0.086	1.74	High
1991 Uttarkashi (Tehri, India) (GM4)	27	7	50.6	25	0.02	0.062	0.092	0.671	Low
1992 Landers (Fort Irwin) (GM5)	FTI0	7.28	66.8	25	0.02	0.113	0.095	1.187	Intermediate
1991 Uttarkashi (Uttarkashi, India) (GM6)	75	7	34	25	0.02	0.31	0.195	1.589	High

3. CONCLUSION

Following conclusions can be drawn for the three, seven, and twenty two-storey regular RC buildings from the results obtained in chapter 5:

Three Storey Regular RC structure

- In x and z direction maximum storey displacement for Three-storey regular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.
- In x direction maximum storey velocity for Three-storey regular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content while high frequency content ground motion result in minimum storey velocity in both x and z direction
- In x direction maximum storey acceleration for Three-storey regular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content while high frequency content ground motion result in minimum storey acceleration in both x and z direction.
- In x and z direction maximum base shear for Three-storey regular RC structure is result of low frequency content ground motion, while minimum base shear is result of high frequency content ground motion.

Seven Storey Regular RC structure

- In x and z direction maximum storey displacement for Seven-storey regular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.
- In x and z direction maximum storey velocity for Seven-storey regular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.
- In x direction maximum storey acceleration for Seven-storey regular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content ground motion while high frequency content ground motion result in minimum storey acceleration in both x and z direction.
- In x and z direction maximum base shear for Seven-storey regular RC structure is result of low frequency content ground motion, while minimum base shear is result of high frequency content ground motion.

Twenty two Storey Regular RC structure

- In x and z direction maximum storey displacement for Twenty two-storey regular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.
- In x and z direction maximum storey velocity for Twenty two-storey regular RC structure is result of low frequency content ground motion, while minimum storey velocity is result of high frequency content ground motion.
- In x and z direction maximum storey acceleration for Twenty two-storey regular RC structure is result of low frequency content ground motion, while minimum storey acceleration is result of high frequency content ground motion.
- In x and z direction maximum base shear for Twenty two-storey regular RC structure is result of low frequency content ground motion, while minimum base shear is result of high frequency content ground motion.

Following conclusions can be drawn for the three, seven, and twenty two-storey irregular RC buildings from the results obtained in chapter 6:

Three Storey Irregular RC structure

- In x direction maximum storey displacement for Three-storey irregular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content ground motion, while high frequency content ground motion result in minimum storey displacement in both x and z direction
- In x direction maximum storey velocity for Three-storey irregular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content while high frequency content ground motion result in minimum storey velocity in both x and z direction

- In x direction maximum storey acceleration for Three-storey irregular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content while high frequency content ground motion result in minimum storey acceleration in both x and z direction.

- In x direction maximum base shear for Three-storey irregular RC structure is result of intermediate frequency content ground motion and for z direction it is due to low frequency content while high frequency content ground motion result in minimum base shear in both x and z direction.

Seven Storey Irregular RC structure

- In x and z direction maximum storey displacement for Seven-storey irregular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.

- In x and z direction maximum storey velocity for Seven-storey irregular RC structure is result of low frequency content ground motion, while minimum storey velocity is result of high frequency content ground motion.

- In x and z direction maximum storey acceleration for Seven-storey irregular RC structure is result of low frequency content ground motion, while minimum storey acceleration is result of high frequency content ground motion.

- In x and z direction maximum base shear for Seven-storey irregular RC structure is result of low frequency content ground motion, while minimum base shear is result of high frequency content ground motion.

Twenty two Storey Irregular RC structure

- In x and z direction maximum storey displacement for Twenty two-storey irregular RC structure is result of low frequency content ground motion, while minimum storey displacement is result of high frequency content ground motion.

- In x and z direction maximum storey velocity for Twenty two -storey irregular RC structure is result of low frequency content ground motion, while minimum storey velocity is result of high frequency content ground motion.

- In x and z direction maximum storey acceleration for Twenty two -storey irregular RC structure is result of low frequency content ground motion, while minimum storey acceleration is result of high frequency content ground motion.

- In x and z direction maximum base shear for Twenty two -storey irregular RC structure is result of low frequency content ground motion, while minimum base shear is result of high frequency content ground motion.

It can be summarized that low-frequency content ground motion has significant effect on both regular as well as irregular RC buildings responses. However, high-frequency content ground motion has very less effect on responses of both regular and irregular RC buildings. It is found that the intermediate-frequency content ground motion has less effect than low-frequency content ground motion and more effect than high-frequency content ground motion on the RC buildings.

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